

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
10 February 2005 (10.02.2005)

PCT

(10) International Publication Number
WO 2005/011959 A1

(51) International Patent Classification⁷: **B29C 67/00**,
67/02, 67/04

(21) International Application Number:
PCT/GB2004/003142

(22) International Filing Date: 20 July 2004 (20.07.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0317387.9 25 July 2003 (25.07.2003) GB

(71) Applicant (for all designated States except US): **LOUGHBOROUGH UNIVERSITY ENTERPRISES LIMITED** [GB/GB]; Loughborough University, Admin 1 Building, Ashby Road, Loughborough, Leicestershire LE11 3TU (GB).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **HOPKINSON, Neil** [GB/GB]; Department of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough,

Leicestershire LE11 3TU (GB). **ERASENTHIRAN, Poonjolai** [MY/GB]; Department of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU (GB).

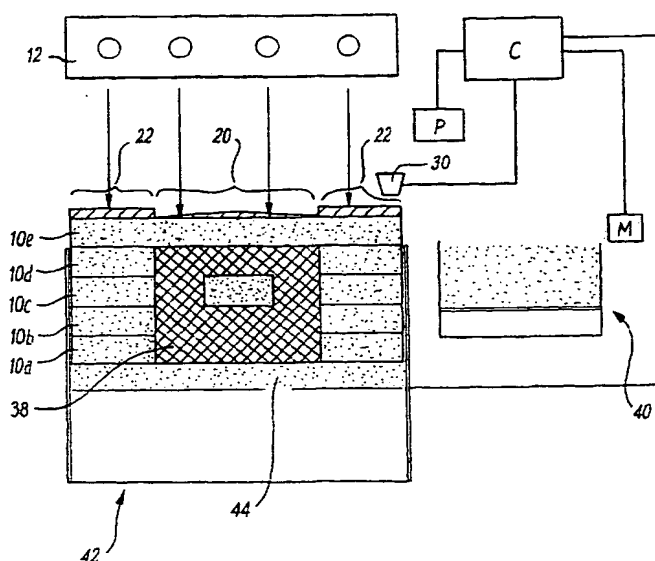
(74) Agent: **HIGGIN, Paul**; Swindell & Pearson, 48 Friar Gate, Derby DE1 1GY (GB).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GI, GM, GR, GU, HK, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI,

[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR COMBINING PARTICULATE MATERIAL



(57) Abstract: A method of selectively combining particulate material, for example plastics material by sintering, comprises providing a layer (10) of particulate material, providing radiation, for example using a radiation source (12), over the layer (10), and varying the absorption of the provided radiation across a selected surface portion of the layer (10) to combine a portion of the material of the layer (10). The method may comprise varying radiation absorption by varying the intensity of the radiation incident on the surface portion of the layer (10), or alternatively may comprise varying the radiation absorptive properties of the particulate material over the selected surface portion of the layer (10), for example by printing a radiation absorbent material (50, Fig. 5) onto the surface portion.



SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

Method and Apparatus for Combining Particulate Material

Embodiments of the present invention relate to a method of selectively combining particulate material and/or apparatus for combining particulate
5 material.

Rapid Prototyping is widely used to form prototype components, and a number of methods are currently available for carrying out rapid prototyping. In one method, a computer generated three dimensional model of the
10 component is initially produced using computer assisted drawing (CAD) software. The three dimensional model is then sliced into a number of virtual layers, and a device used to form and combine the layers to create the three dimensional component.

15 It is known to form the respective layers by combining particulate material using a laser that sinters the particulate material. However, this method can be disadvantageous since the laser must pass over the entire surface of each layer, which can be time consuming. As an alternative, infra-red radiation can be provided on selected portions of a layer of particulate
20 material to combine it. However, the accuracy of the components produced using this method may be unsatisfactory.

According to a first aspect of the present invention, there is provided a method of selectively combining particulate material, comprising the steps of:
25

- (i) providing a layer of particulate material;
- (ii) providing radiation over the layer of particulate material; and
- (iii) varying the absorption of the provided radiation across a selected surface portion of the layer to combine a portion of the
30 material of the layer.

According to a second aspect of the present invention, there is provided apparatus for combining particulate material, the apparatus comprising a controller for enabling the exposure of a surface portion of a

layer of particulate material to radiation, wherein the controller is arranged to control the variation of radiation absorption across said surface portion.

5 Preferred features of the invention are defined in the accompanying claims.

The surface portion that receives variable radiation absorption may be a part, and not the whole, of the surface of the layer of particulate material.

10 The provision of variable radiation absorption across the surface portion requires the existence of multiple areas in which the absorption of radiation is different and greater than zero.

15 According to one embodiment, the variable radiation absorption across the surface portion may be provided by varying the intensity of the provided radiation incident on the surface portion of the layer of particulate material.

20 According to a different embodiment, the variable radiation absorption across the surface portion may be provided by varying the absorptive properties of the particulate material across the selected surface portion of the layer.

Embodiments of the present invention will now be described by way of example only and with reference to the accompanying drawings, in which:-

25

Fig. 1 is a diagrammatic illustration of a first embodiment of apparatus for combining particulate material;

30

Fig. 2 is a diagrammatic plan view of a surface portion of a layer of particulate material;

Fig. 3 is a diagrammatic illustration of a second embodiment of apparatus for combining particulate material;

Fig. 4 is a diagrammatic view of a third embodiment of apparatus for combining particulate material;

5 Fig. 5 is a diagrammatic view of a fourth embodiment of apparatus for combining particulate material;

Fig. 6a is a further diagrammatic plan view of a surface portion of a layer of particulate material;

10 Fig. 6b is a side view of the layer of particulate material of Fig. 6a;

Fig. 7 is a diagrammatic schematic view of apparatus for combining particulate material being used to form a three dimensional object; and

15 Fig. 8 is a diagrammatic view of the apparatus of Fig. 1 being used to combine different types of particulate material.

Referring to the drawings, there is shown generally apparatus for combining particulate material, for example plastics material by sintering, the
20 apparatus comprising a controller C for enabling the exposure of a surface portion of a layer 10 of particulate material to radiation, for example infra-red radiation provided by a radiation source 12, the controller C being arranged to control the variation of radiation absorption across the surface portion.

25 In more detail, Fig. 1 illustrates a first embodiment of apparatus for sintering particulate material in which an obscurer 14 (i.e. a mask) is provided for selectively obscuring the radiation provided by the source 12 on the surface portion of the layer 10 to thereby vary the intensity of the radiation incident on the surface portion of the layer 10. The obscurer 14 comprises a
30 radiation transmissive substrate 16, such as a glass plate, which carries a varying amount of radiation reflective material 18, such as aluminium oxide. The amount and pattern of material 18 deposited on the substrate may be varied to selectively vary the intensity of radiation incident on the surface portion of the layer 10, as will be described hereinafter.

Referring also to Fig. 2, the surface portion of the layer 10 is logically divided by the obscurer 14 into a number of areas including a combination portion 20, which is to be exposed to radiation to combine the particulate material, and a non-combination portion 22 which is to be shielded, or at least substantially shielded, from radiation to prevent combination of the particulate material by sintering. Full shielding of the non-combination portion 22 is not essential, provided that the intensity of radiation transmitted to the non-combination portion 22 is such that the particulate material is not heated to its sintering temperature. In some circumstances, transmission of low intensity radiation onto the non-combination portion 22 to heat the material can be desirable and can result in improved accuracy of the finished component. This is because heating material in the non-combination portion 22 reduces the thermal gradient between the material in the combination portion 20 and the non-combination portion 22.

The combination portion 20 is logically divided by the obscurer 14 into a central portion 24 and an edge portion 26, and reflective material 18 is deposited onto the substrate 16 such that a greater amount of the material 18 is provided on the central portion 24 than on the edge portion 26 where no reflective material 18 may be provided. Consequently, the intensity of radiation provided across the surface of the combination portion 20 increases from a minimum value at the central portion 24 to a maximum value at the edge portion 26 where the surface of the layer 10 of particulate material is fully exposed to radiation provided by the radiation source 12.

The layer of reflective material is schematically illustrated in Fig. 1. The variation of thickness of the layer in the figure does not illustrate a variation of thickness of the layer in practice but illustrates a variation in the amount of the material. Where the layer is thick in the figure, in practice there will be a large amount of the material present.

Although the combination portion 20 has been shown to have only one edge portion 26 such that the central portion 24 is located at the centre of the

combination portion 20, it should be appreciated that the combination portion 20 may for example be of annular configuration such that the central portion 24 is bounded on two sides by edge portions 26. Moreover, it is not essential that the central portion 24 is located at the centre of the surface portion of the layer 10 of particulate material.

The controller C is arranged to control a motor 28 for moving the obscurer 16 from an obscuring position in which it overlies the layer 10, as shown in Fig. 1, to a non-obscuring position in which it does not overlie the layer 10. The controller C is also arranged to control a deposition device, such as a printing head 30, for depositing the reflective material 18 onto the substrate 16. The controller C controls the amount of material 18 deposited by the head 30 onto each part of the substrate 16. In the embodiment shown in Fig. 1, the head 30 remains stationary and deposits reflective material 18 onto the substrate 16 as the motor 28 moves the substrate 16 past the head 30. In an alternative embodiment (not shown), the substrate 16 may remain stationary, overlying the layer 10, and the motor 28 may move the printing head 30 over the substrate 16 to deposit reflective material 18 thereon.

In the illustrated embodiment, the reflective material 18 is contemporaneously printed onto the substrate 16 during operation of the apparatus. The amount of material 18 printed onto the substrate 16 by the head 30 may be varied by the controller C according to the surface temperature of the layer 10. The surface temperature of the layer 10 may be measured by a temperature measuring device, such as, for example, a pyrometer P or a thermal imaging camera, and surface temperature measurements are communicated in real time to the controller C. A wiping arrangement (not shown) may be provided for removing reflective material 18 from the substrate 16, so that it can be re-used. Different amounts of material 18 can be deposited onto the substrate 16, in dependence on the desired radiation intensity profile at the substrate surface.

Alternatively, the reflective material 18 may be pre-printed onto the substrate 16 prior to operation of the apparatus and the same pre-printed

substrate 16, or a number of pre-printed substrates 16, may be used, one for each layer 10 of particulate material. In this case, measurement of the surface temperature using pyrometer P may not be needed. The use of a plurality of pre-printed substrates 16 is particularly advantageous when there is a need to
5 produce a large quantity of the same component since it reduces the time taken to sinter each layer of material and hence produce the prototype component, increases repeatability and leads to a reduction in the cost of producing the components.

10 It should also be noted that it is within the scope of the present invention to utilise a plurality of pre-printed substrates 16, or to contemporaneously print different amounts of reflective material 18 onto the same substrate 16, and to use these to expose the same layer 10 of material to different radiation intensity profiles in multiple exposure steps.

15 Fig. 3 illustrates a second embodiment of apparatus for combining particulate material, in which corresponding elements are given corresponding reference numerals. The apparatus of Fig. 3 is similar to that shown in Fig. 1, except that instead of the reflective material 18 being deposited onto a
20 substrate 16, the reflective material 18 is deposited, using the printing head 30, directly onto the surface portion of the layer 10 of particulate material.

In the apparatus of this embodiment, the printing head 30 is again controlled by the controller C which controls both the movement of the head
25 30 across the surface of the layer 10 and the rate of deposition of reflective material 18 onto the layer 10. Again, real time measurement of the surface temperature of the layer 10 may be carried out using a temperature measurement device, for example, a pyrometer P or thermal imaging camera, the temperature measurement being used by the controller C to determine the
30 amount of reflective material 18 to be printed by the head 30 onto the surface portion of the layer 10.

The layer of reflective material is schematically illustrated in Fig. 3. The variation of thickness of the layer in the figure does not illustrate a variation of

thickness of the layer in practice but illustrates a variation in the amount of the material. Where the layer is thick in the figure, in practice there will be a large amount of the material present.

5 Fig. 4 illustrates a third embodiment of apparatus for combining particulate material which is similar to the first and second embodiments and in which corresponding elements are given corresponding reference numerals. In this embodiment, the controller C is arranged to selectively redirect the radiation provided by the source 12 and thereby vary the radiation
10 intensity incident across the surface portion of the layer 10. Selective redirection of the radiation is achieved by controlling, using the controller C, a plurality of mirrors 34 which form a Digital Mirror Device (DMD) 36. Each mirror 34 is adjustable by the controller to an operative position, in which radiation is fully redirected onto the surface portion of the layer 10, or to an
15 inoperative position in which radiation is fully redirected away from the surface portion. By providing an array of mirrors 34, the surface portion of the layer 10 can be effectively divided into an array of segments, as discussed hereinafter, and the intensity of the radiation incident on each segment can be varied, according to a bitmap image, by selectively varying the frequencies at which
20 individual mirrors 34 are moved between the operative and inoperative positions.

Use of a temperature measurement device, such as a pyrometer P, although optional is particularly advantageous with the apparatus of this
25 embodiment as the position of each mirror 34 can be instantaneously controlled, in real time, by the controller C in response to instantaneous temperature variations across the surface portion of the layer 10.

Fig. 5 illustrates a fourth embodiment of apparatus for combining
30 particulate material which is similar to the embodiments described above and in which corresponding elements have been given corresponding reference numerals.

The apparatus of Fig. 5 is most similar to the apparatus of Fig. 3 in that material is deposited directly onto the surface portion of the layer 10 of particulate material. However, according to the fourth embodiment, the material is a radiation absorbent material 50, for example a material such as carbon black in powder form. In use, radiation provided by the radiation source 12 is absorbed by the radiation absorbent material 50 where it is present on the surface, causing the radiation absorbent material 50 to heat up. Heat from the radiation absorbent material 50 is radiated to the underlying particulate material raising the temperature of individual particles of the particulate material. As the particles are heated to a temperature approaching their melting temperature, they neck and coalesce with adjacent heated particles. As the temperature subsequently decreases, the particles form a coherent mass of combined particulate material.

The deposition of a radiation absorbent material 50 directly onto the surface portion of the layer 10 enables the radiation absorptive properties of the particulate material to be varied and carefully controlled, as desired. In particular, varying the amount of the radiation absorbent material 50 on the surface enables the variation of the radiation absorptive properties of the surface portion of the underlying layer 10 of particulate material. In areas where there is a greater amount of the radiation absorbent material 50, a greater amount of the radiation provided by the radiation source 12 is absorbed. This provides for a greater amount of heat transfer to the underlying particulate material thereby heating it to a higher temperature and causing it to combine more rapidly. In areas where there is less absorbent material 50, there is lower radiation absorption and hence less heat transfer to the underlying particulate material, causing it to combine at a slower rate.

In areas where no radiation absorbent material 50 is provided and pure particulate material is exposed to the radiation provided by the radiation source 12, there will be insufficient absorption of the radiation to heat the particulate material to its melting temperature. Thus, there will be no combination of the particulate material in areas where no radiation absorbent material 50 is provided.

The layer of radiation absorbent material 50 is schematically illustrated in Fig. 5. The variation of thickness of the layer in the figure does not illustrate a variation of thickness of the layer in practice but illustrates a variation in the amount of the material. Where the layer is thick in the figure, in practice there will be a large amount of the material present.

As with the embodiments of Figs. 1 and 3, it is desirable to provide for a greater amount of radiation absorption at the edge portion 26 of the combination portion 20 than at the central portion 24. Accordingly, the amount of the radiation absorbent material 50 decreases from a maximum value at the edge portion 26 to a minimum value at the central portion 24.

As illustrated, no radiation absorbent material 50 is provided on the surface portion of the layer 10 of the particulate material in the non-combination portion 22. For the reasons explained above, there will be no combination of the particulate material in the non-combination portion 22 when the layer 10 is exposed to radiation. There may however be some heating of the particulate material in the non-combination portion 22, and this can be advantageous to minimise the thermal gradient between the particulate material in the combination portion 20 and the non-combination portion 22, as already discussed.

As with the embodiment of Fig. 3, the printing head 30 is operable to deposit desired amounts of the radiation absorbent material 50 onto the surface portion of the layer 10, and the movement of the printing head 30 and the amount of material 50 deposited by the head 30 is controlled by the controller C. Again, the pyrometer P or a thermal imaging camera may be used to measure the surface temperature of the layer 10, the amount of radiation absorbent material 50 deposited being varied by the controller C in accordance with the temperature measurements.

The applicant has appreciated that when the particulate material is combined by sintering at a slow rate, the combined material has good material

properties, for example high strength, but has poor definition at the edge portion 26. The poor edge definition arises because as the particulate material combines, there is some shrinkage which causes unwanted movement of uncombined particulate material from the non-combination portion 22 towards the combination portion 20. On the other hand, when the particulate material is combined by sintering at a rapid rate, the combined material has inferior material properties, but has good edge definition since the particulate material in the edge portion 26 is rapidly combined and locked in position, thereby minimising unwanted movement of surrounding uncombined particulate material.

In order to provide a layer 10 of combined particulate material having good material properties and good definition at the edge portion 26, it is thus desirable to cause the particulate material in the combination portion 20 to combine at a slow rate to provide good material properties, and to cause the particulate material at the edge portion 26 to combine rapidly to provide good edge definition.

One method by which this can be achieved is to use the apparatus according to the different embodiments of the invention described above to provide for greater absorption of radiation at the edge portion 26 than over the remainder of the combination portion 20. This can be achieved by varying the intensity of the radiation incident on the selected surface portion of the layer 10 using the apparatus according to the first, second or third embodiments, or by varying the absorption of the radiation across the selected surface portion by providing a variable amount of radiation absorbent material 50 across the surface portion. In all of the above cases, radiation is provided over the layer 10 in a single exposure step.

Using the apparatus according to the fourth embodiment of the invention, similar results may be achieved by providing radiation over the layer 10 of particulate material in multiple exposure steps, as will now be discussed.

According to a first method, a constant first amount of radiation absorbent material 50 is provided over the combination portion 20, and radiation is then provided over the layer 10, using the radiation source 12, to cause the underlying particulate material in the combination portion 20 to combine. The first amount of radiation absorbent material 50 is selected to be a relatively low amount so that the underlying particulate material combines at a slow rate and has good material properties.

After the particulate material has been combined, further particulate material is added to the layer 10 at the edge portion 26 where there will have been shrinkage. A second amount of the same radiation absorbent material 50, which is greater than the first amount, is then provided over the edge portion 26, and radiation is again provided over the layer 10 using the radiation source 12. The second amount of material is selected to be a relatively high amount so that the underlying particulate material is caused to combine at a rapid rate. Due to the increased amount of radiation absorbent material 50 present at the edge portion 26, and hence the rapid combination of the underlying particulate material, material shrinkage is minimised thus providing the resultant layer 10 of combined material with good definition at the edge portion 26.

According to a second method, a constant amount of a first radiation absorbent material 50 having a first natural radiation absorbency is provided over the combination portion 20, and radiation provided over the layer 10, using the radiation source 12, to cause the underlying particulate material in the combination portion 20 to combine. The first radiation absorbent material 50 is selected to have a low natural radiation absorbency so that a relatively low amount of the radiation is absorbed and so that the underlying particulate material combines at a slow rate and has good material properties.

30

After the particulate material has been combined, further particulate material is added to the layer 10 at the edge portion 26 where there will have been shrinkage. A second different radiation absorbent material 50, having a second natural radiation absorbency, is then provided over the edge portion

26, and radiation is again provided over the layer 10 using the radiation source 12. The second radiation absorbent material 50 is selected to have a high natural radiation absorbency, which is higher than the absorbency of the first radiation absorbent material 50, so that a high amount of the radiation is absorbed and so that the underlying particulate material in the edge portion 26 combines at a rapid rate.

According to a third method, a first radiation absorbent material 50 capable of absorbing a first wavelength of radiation is provided over the combination portion 20, and radiation of a first wavelength is then provided over the layer 10, using the radiation source 12, to cause the underlying particulate material in the combination portion 20 to combine.

After the particulate material has been combined, further particulate material is added to the layer 10 at the edge portion 26 where there will have been shrinkage. A second radiation absorbent material 50, capable of absorbing a second different wavelength of radiation, is then provided over the edge portion 26, and radiation of a second wavelength is provided over the layer 10 using the radiation source 12.

In order to provide the desired material properties in the combination portion 20, the radiation at the first wavelength may be selected to have a relatively low intensity so that the first radiation absorbent material 50 is heated at a slow rate thereby causing the underlying particulate material to combine at a slow rate. In order to provide good definition at the edge portion 26, the radiation at the second wavelength may be selected to have a relatively high intensity so that the second radiation absorbent material 50 is heated rapidly thereby causing the underlying particulate material to combine at a rapid rate.

Alternatively, a greater amount of the second radiation absorbent material 50 than the first radiation absorbent material 50 may be provided, as described above with reference to the first method, and the radiation of the

first and second wavelengths provided by the radiation source 12 selected to have the same intensity.

5 As a further alternative, the second radiation absorbent material 50 may be selected to have a higher natural radiation absorbency than the first radiation absorbent material 50, as described above with reference to the second method, and the radiation of the first and second wavelengths provided by the radiation source 12 selected to have the same intensity.

10 If desired, the third method could be adapted so that the first and second radiation absorbent materials 50 are simultaneously applied to the surface of the layer of particulate material, and the radiation of the first and second wavelengths provided in separate steps.

15 It is possible that the first, second and third methods described above could be modified so that the particulate material at the edge portion 26 of the layer 10 is initially caused to combine at a rapid rate to lock the edge portion 26, and the particulate material in the remainder of the combination portion 20 is subsequently caused to combine at a slow rate to provide the desired material properties.

Referring now to Figs. 6a and 6b, the apparatus according to the invention allows the surface portion of the layer 10 of particulate material to be logically divided into an array of segments 32. The controller can control the
25 amount of radiation absorption on each segment 32 independently and a bitmap image can be used to specify the amount of radiation that should be absorbed at the surface portion. The greyscale of each segment 32 of the bitmap image is individually adjustable, and in the case of the first and second embodiments of the apparatus, the amount of reflective material 18 deposited
30 onto each segment of the substrate 16 or surface portion of the layer 10 is individually adjustable, according to the bitmap image, to provide any desired radiation intensity profile over the surface portion of the layer 10. When the apparatus of the third embodiment is employed, the mirrors 34 are adjusted to vary the intensity of radiation incident on each segment 32 of the array. When

the apparatus of the fourth embodiment is used, the amount of radiation absorbent material 50 deposited onto each segment of the surface portion of the layer 10 is individually adjustable, according to the bitmap image, to provide any desired radiation absorption profile over the surface portion of the layer 10.

In the arrangement shown in Figs. 6a and 6b, a first amount of reflective material 18 has been deposited by printing head 30 onto the segments 32 defining the central portion 24 of the combination portion 20. Accordingly, a first intensity of radiation, which is less than the maximum intensity, is incident on the surface portion of the layer 10 located beneath these segments 32. The first intensity of radiation is sufficiently high to raise the temperature of the particulate material to cause it to combine.

No reflective material 18 has been provided on the segments 32 which define the edge portion 26 of the combination portion 20, thereby allowing a maximum intensity of radiation to reach the surface portion of the layer 10 located beneath these segments 32. The maximum intensity of radiation causes the particulate material located beneath the segments 32 defining the edge portion 26 to combine more quickly than particulate material in the central portion 24.

A second amount of reflective material 18, which is greater than the first amount, is deposited by printing head 30 onto the segments 32 defining the non-combination portion 22. A sufficient amount of material 18 may be provided to prevent transmission of any radiation to the surface portion of the layer 10 located beneath these segments 32. Consequently, the particulate material located beneath these segments 32 does not combine.

Whilst variation of the radiation intensity on each individual segment 32 has been described with respect to the second embodiment of the apparatus, it is to be understood that the same effect can be achieved using apparatus according to the first embodiment, in which reflective material 18 is printed onto a substrate 16, according to the third embodiment, in which mirrors 34

are used to vary the intensity of radiation incident on each segment 32, or according to the fourth embodiment in which radiation absorbent material 50 is printed onto the surface portion of the layer 10 of particulate material.

5 The layer of reflective material is schematically illustrated in Fig. 6b. The variation of thickness of the layer in the figure does not illustrate a variation of thickness of the layer in practice but illustrates a variation in the amount of the material. Where the layer is thick in the figure, in practice there will be a large amount of the material present.

10

Referring now to Fig. 7, there is shown a diagrammatic illustration of the apparatus of Fig. 3 being used to form a three dimensional object 38. Again, elements of the apparatus which have been referred to above are given corresponding reference numerals.

15

The apparatus is used to form a three dimensional object 38 by combining a plurality of layers 10a to 10e of particulate material. A supply of particulate material, for example Nylon powder, is provided in a supply tank 40 and the controller C is arranged to control a motor M which can move
20 particulate material from the tank 40 into a building device 42, which includes a vertically movable platform 44. Movement of the platform 44 is controlled by the controller C, such that the platform 44 is moved vertically downwards in discrete steps after each layer 10 has been formed.

25

Initially, with the platform 44 in an uppermost position, the controller C actuates the motor M to provide a first layer 10a of particulate material on the platform 44. The controller C then actuates the printing head 30 to deposit a desired pattern of reflective material 18 onto the surface portion of the layer 10 of material. Alternatively, the reflective material 18 may be deposited by
30 the printing head 30 onto a substrate 16, as previously discussed, or the intensity incident at the surface may be controlled using digital mirrors.

The controller C then activates the radiation source 12 to provide radiation over a selected surface portion of the layer 10, as defined by the

reflective material 18. As shown in Fig. 7, radiation is provided with varying intensity across the combination portion 20 and the material in this portion is combined. The reflective material 18 prevents, or at least substantially prevents, transmission of radiation to the surface portion of the material in the non-combination portion 22 where the material is not combined and remains in particulate form. The varying amount of reflective material 18 thus provides for variable intensity radiation across the combination portion 20 of the layer 10.

10 After combination of the material in the combination portion 20 of the first layer 10a has been carried out, the controller C deactivates the radiation source 12 and lowers the platform 44 by a distance approximately equivalent to the desired layer thickness. The controller C then actuates the motor M to provide a second layer 10b of particulate material overlying the first layer 10a including a previously combined portion of material. The controller C then
15 actuates the printing head 30 to deposit reflective material 18 onto the surface portion of the second layer 10b. The amount and pattern of reflective material 18 deposited onto the surface portion of the second layer 10b may be the same as that provided on the first layer 10a, or may be different, for example
20 in response to design or surface temperature measurements carried out using the pyrometer P. The controller C then activates the radiation source 12 to provide radiation across the surface portion of the second layer 10b, the reflective material 18 providing for variable intensity radiation across the surface portion. The material in the combination portion 20 of the second layer
25 10b is thus caused to combine, and also to combine with the previously combined portion of material in the first layer 10a. The adjacent layers 10a, 10b are thus combined to form part of a coherent object 38.

30 The controller C continues to operate in this manner to provide further layers 10c to 10e of particulate material and combine them, until formation of the object 38 has been completed. Once the coherent object 38 has been formed, the platform 44 is raised by the controller C to eject the combined object 38 and any remaining uncombined particulate material surrounding the object 38 from the device 42.

Again, it should be appreciated that the apparatus according to any of the other embodiments of the invention may be used to form a three dimensional object 38.

5

Fig. 8 illustrates use of the apparatus of Fig. 1 to combine different particulate materials P1 and P2 which are located adjacent to each other in a layer 10. By way of illustration, the material P1, for example copper, may have a lower melting point than the material P2, for example steel, and may therefore combine by sintering at a lower temperature. The concentration of material P2 decreases from right to left across a transition gradient region 19. The concentration of material P1 decreases from left to right across the transition gradient region 19.

15

In order to ensure optimum material characteristics and minimise thermal stresses over the gradient region 19 between the materials P1 and P2, the substrate 16 may be provided with a high amount of reflective material 18 on the portion overlying the material P1 of the layer 10, a low amount of reflective material on the portion overlying the material P2 and an amount of reflective material over the gradient region 19 that decreases from left to right in the figure. By varying radiation intensity in this way, the materials P1 and P2 are heated to different temperatures using a fixed intensity radiation source 12 and are simultaneously combined to form a coherent layer.

20

25

The layer of reflective material 18 is schematically illustrated in Fig. 8. The variation of thickness of the layer in the figure does not illustrate a variation of thickness of the layer in practice but illustrates a variation in the amount of the material. Where the layer is thick in the figure, in practice there will be a large amount of the material present

30

Whilst the first embodiment of the apparatus has been described for use in combining the dissimilar particulate materials P1 and P2, it will be readily appreciated that the second embodiment of the apparatus in which reflective material 18 is printed directly onto the surface portion of the layer

10, the third embodiment of the apparatus which uses mirrors 34 to selectively redirect radiation, or the fourth embodiment of the apparatus in which radiation absorbent material 50 is printed directly onto the surface portion of the layer 10, could alternatively be used.

5

In any of the above described embodiments, it may be desirable to add radiation absorbing material to the particulate material to increase the absorption of radiation. For example, a material such as carbon black may be used for this purpose.

10

Other particulate materials, such as ceramic filler powder, may be added to the particulate material to improve the material properties of the resultant component.

15

Where different radiation absorbent materials are employed, for example as described above with reference to Fig. 5, these may be of different colours to provide the resultant component with desired aesthetic properties.

20

Although embodiments of the invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated the various modifications to the examples given may be made without departing from the scope of the present invention, as claimed. For example, although the use of infra-red radiation is described, radiation other than infra-red may be used, provided that it is able to elevate the particulate material to a temperature at which it combines by sintering. The source of radiation may be of any suitable type, for example, LEDs, a scanning laser or a halogen source. The particulate material that is combined by the above described embodiments may be any suitable material, such as a metal, ceramic etc. A device other than a motor M may be used to move particulate material from the supply tank 40 to the combination device 42. The combination device 42 may be of a different configuration to that shown. Any number of different types of particulate material may be provided in a layer 10. Alternatively, different types of particulate material may be provided in

25

30

adjacent layers. Reflective material 18 may be deposited onto a lower surface of the substrate 16 rather than an upper surface, as illustrated. Different materials may be used for the reflective material 18 and the substrate 16. Any suitable material may be used for the radiation absorbent material 50. For
5 example, a liquid suspension and/or a gas, for example carbon dioxide, could be employed instead of a powder material. The digital mirror device described in relation to Fig. 4 could be replaced by a series of diffractive optics, one for each layer.

10 Whilst endeavouring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance, it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or
15 shown in the drawings, whether or not particular emphasis has been placed thereon.

Claims

1. A method of selectively combining particulate material, comprising the steps of:

5

- (i) providing a layer of particulate material;
- (ii) providing radiation over the layer of particulate material; and
- (iii) varying the absorption of the provided radiation across a selected surface portion of the layer to combine a portion of the material of the layer.

10

2. A method according to claim 1, wherein step (iii) comprises providing a first level of radiation absorption on a first area of the selected portion and a second different level of radiation absorption on a second area of the selected portion, contiguous with the first area.

15

3. A method according to claim 2, wherein step (iii) comprises providing a third different level of radiation absorption on a third area of the selected portion, contiguous with the second area.

20

4. A method according to claim 2 or claim 3, wherein step (i) comprises providing a first particulate material in the first area and a second different particulate material in the second area of the layer.

25 5. A method according to claim 1, wherein step (ii) comprises providing radiation on a combination area in which particulate material is to be combined, the combination area including a centre portion and an edge portion, and step (iii) comprises providing greater radiation absorption at the edge portion than at the centre portion.

30

6. A method according to claim 5, wherein the absorption of the radiation increases from a minimum value at the centre portion to a maximum value at the edge portion.

7. A method according to claim 5 or claim 6, wherein step (ii) comprises providing radiation on a non-combination area contiguous with, and external to, the combination area, and step (iii) comprises varying the absorption of the provided radiation so that the absorption of the radiation over the non-combination area is less than the absorption of the radiation over the edge portion of the combination area.
8. A method according to claim 7, wherein the absorption of the radiation over the non-combination area is less than the absorption of the radiation over the centre portion of the combination area.
9. A method according to any of the preceding claims, wherein step (iii) comprises logically dividing the surface area of the selected portion into an array of segments, and providing a different level of radiation absorption on different segments in the array.
10. A method according to claim 9, wherein step (iii) comprises creating a bitmap image that divides the surface area into a plurality of segments.
11. A method according to any of the preceding claims, wherein step (iii) comprises providing variable intensity radiation over the selected surface portion of the layer to vary the radiation absorption.
12. A method according to claim 11, wherein step (iii) comprises selectively obscuring the provided radiation to vary its intensity at the surface of the layer of particulate material.
13. A method according to claim 11, further comprising providing varying amounts of radiation reflective material over the selected surface portion of the layer to vary the intensity of radiation over the selected surface portion of the layer.

14. A method according to claim 11, wherein step (iii) comprises selectively redirecting the provided radiation to vary its intensity at the surface of the layer of particulate material.
- 5 15. A method according to any of claims 1 to 10, wherein step (iii) comprises varying the radiation absorptive properties of the particulate material over the selected surface portion of the layer to vary the radiation absorption.
- 10 16. A method according to claim 15, wherein step (iii) comprises providing varying amounts of radiation absorbent material over the selected surface portion of the layer to vary the radiation absorptive properties of the particulate material over the selected surface portion of the layer.
- 15 17. A method according to claim 15 or claim 16, wherein step (iii) comprises providing radiation absorbent material for absorbing a first wavelength of radiation over a first area of the selected surface portion, and providing radiation absorbent material for absorbing a second different wavelength of radiation over a second area of the selected surface portion.
- 20 18. A method according to claim 17, wherein the method comprises providing radiation having a first wavelength over the layer of particulate material to combine the material in the first area, and providing radiation having a second wavelength over the layer of particulate material to combine the material in the second area.
- 25 19. A method according to any of the preceding claims, comprising the steps of:
- 30 (iv) providing a further layer of particulate material overlying a prior layer of particulate material including a previously combined portion of material;
- (v) repeating steps (ii) and (iii) to combine a further portion of the material within the overlying further layer and to combine said

further portion with the previously combined portion of material in the prior layer.

20. A method according to claim 19, wherein steps (iv) and (v) are
5 successively repeated to form a three dimensional object.

21. Apparatus for combining particulate material, the apparatus comprising
a controller for enabling the exposure of a surface portion of a layer of
particulate material to radiation, wherein the controller is arranged to control
10 the variation of radiation absorption across said surface portion.

22. Apparatus according to claim 21, wherein the controller is responsive
to temperature variation across the surface portion and is arranged to control
the variation of radiation absorption in response to the temperature variation.
15

23. Apparatus according to claim 21 or claim 22, wherein the controller is
arranged to control the variation of radiation intensity provided across said
surface portion.

20 24. Apparatus according to claim 23, wherein the controller is arranged for
selectively obscuring the radiation to vary the radiation intensity across the
surface portion.

25 25. Apparatus according to any of claims 21 to 24, wherein the apparatus
comprises an obscurer for selectively obscuring the radiation provided on the
surface portion and the controller is arranged to control the obscurer for
varying the radiation intensity across the surface portion.

30 26. Apparatus according to claim 25, wherein the obscurer comprises a
radiation transmissive substrate carrying reflective material and overlying the
surface portion and the controller is arranged to control deposition of the
reflective material onto the substrate.

27. Apparatus according to claim 23 or claim 24, wherein the controller is arranged to control the deposition of varying amounts of reflective material directly onto the surface portion of the layer of particulate material.

5 28. Apparatus according to claim 23 or claim 24, wherein the controller is arranged for selectively redirecting the radiation to vary the radiation intensity across the surface portion.

29. Apparatus according to claim 28, wherein the controller is arranged to
10 control a plurality of mirrors to selectively redirect the radiation.

30. Apparatus according to claim 21 or claim 22, wherein the controller is arranged to control the variation of radiation absorptive properties of the particulate material across said surface portion to control the variation of
15 radiation absorption.

31. Apparatus according to claim 30, wherein the controller is arranged to control the deposition of varying amounts of radiation absorbent material directly onto the surface portion of the layer of particulate material to vary the
20 radiation absorptive properties of the particulate material.

32. Apparatus according to claim 31, wherein the controller is arranged to control the deposition of different radiation absorbent materials capable of absorbing different wavelengths of radiation directly onto the surface portion
25 of the layer, and to enable the exposure of the surface portion to radiation of different wavelengths.

33. A method of selectively combining particulate material substantially as hereinbefore described with reference to the accompanying drawings.
30

34. A method of selectively combining particulate material, comprising the steps of:

(i) providing a layer of particulate material;

- (ii) providing varying amounts of radiation absorbent material over a selected surface portion of the layer of particulate material; and
- (iii) providing radiation to combine a portion of the material of at least the layer of particulate material.

5

35. Apparatus for combining particulate material, the apparatus comprising a controller for enabling the exposure of a surface portion of a layer of particulate material to radiation, wherein the controller is arranged to control the variation of radiation absorption across said surface portion by controlling the deposition of varying amounts of radiation absorbent material over the layer of particulate material.

10

36. Apparatus for combining particulate material substantially as hereinbefore described with reference to the accompanying drawings.

15

37. Any novel subject matter or combination including novel subject matter disclosed herein, whether or not within the scope of or relating to the same invention as any of the preceding claims.

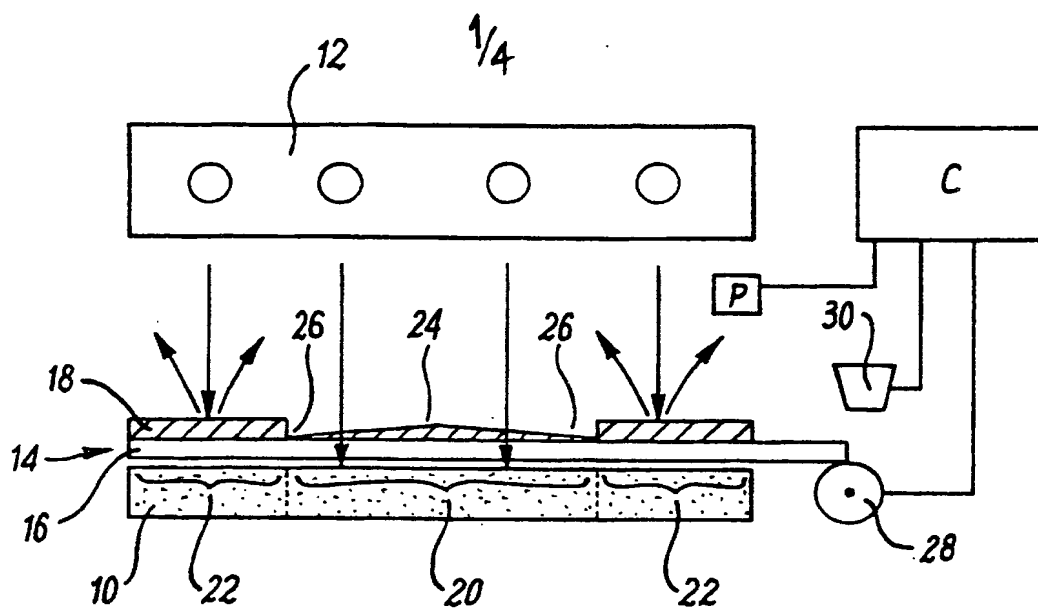


FIG. 1

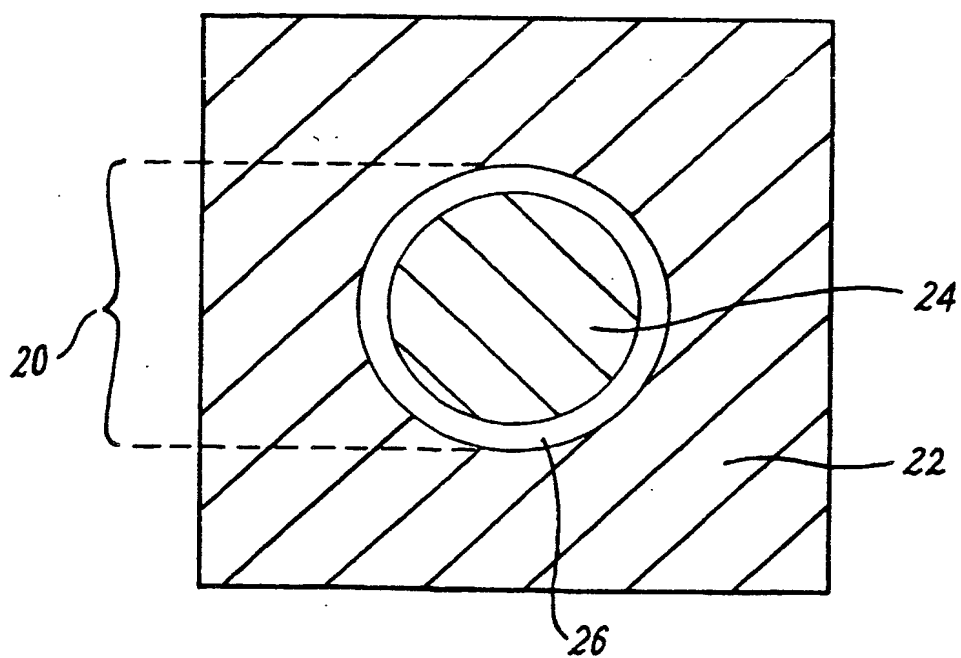


FIG. 2

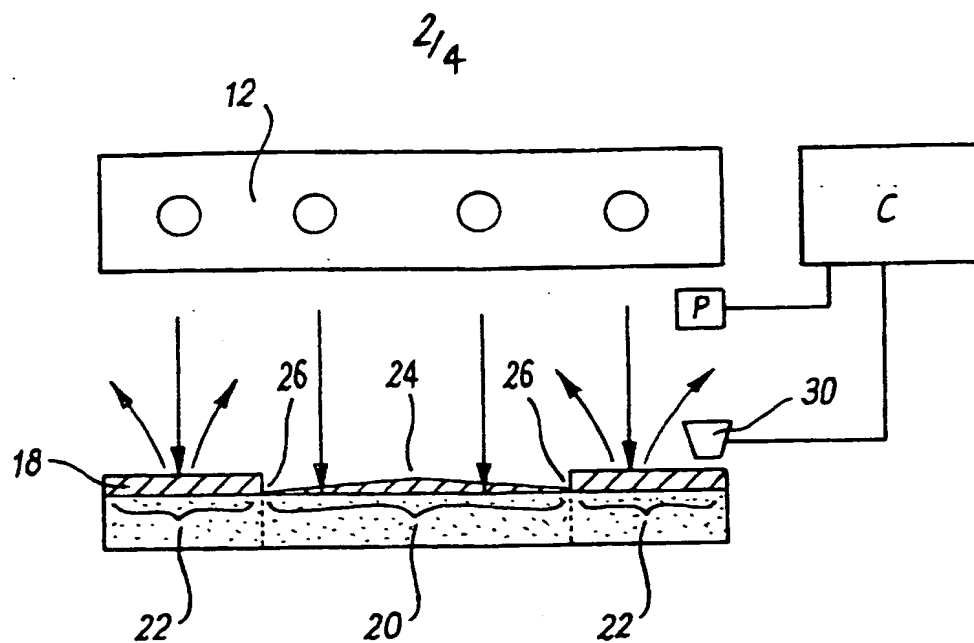


FIG. 3

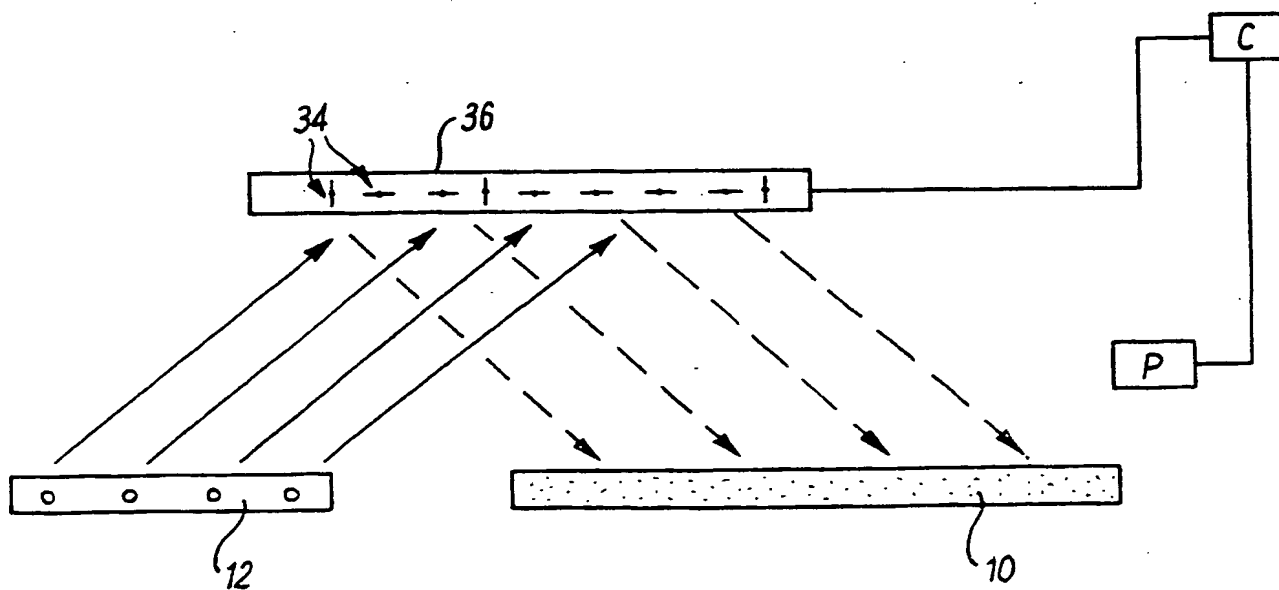
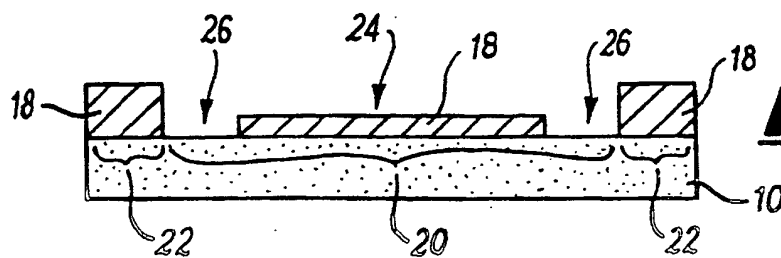
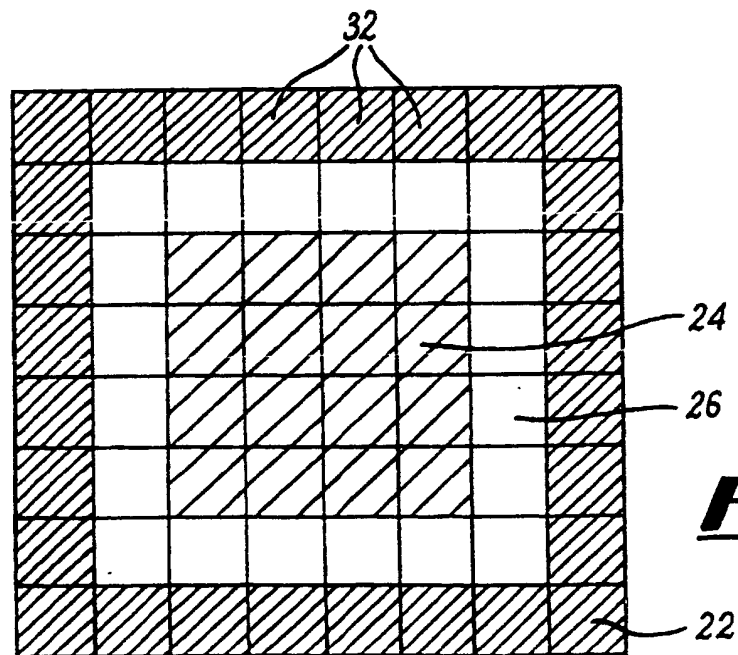
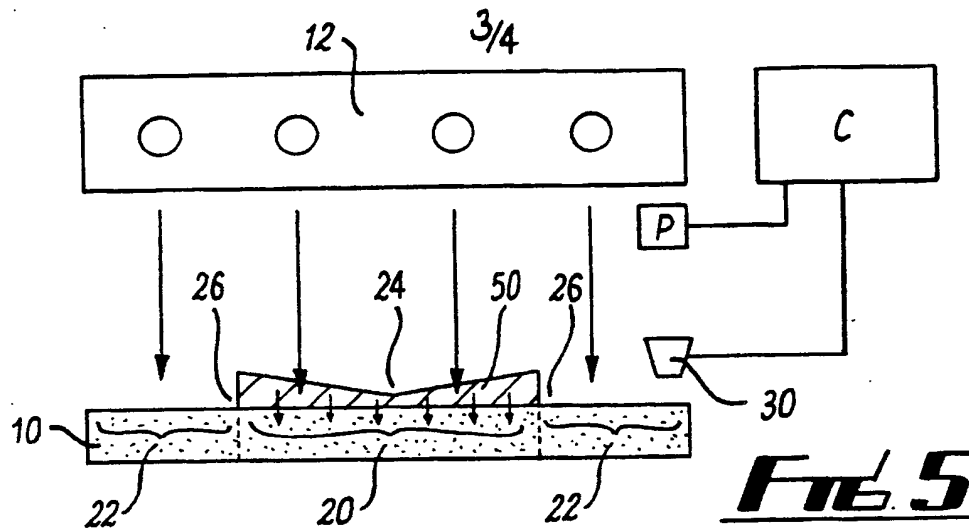
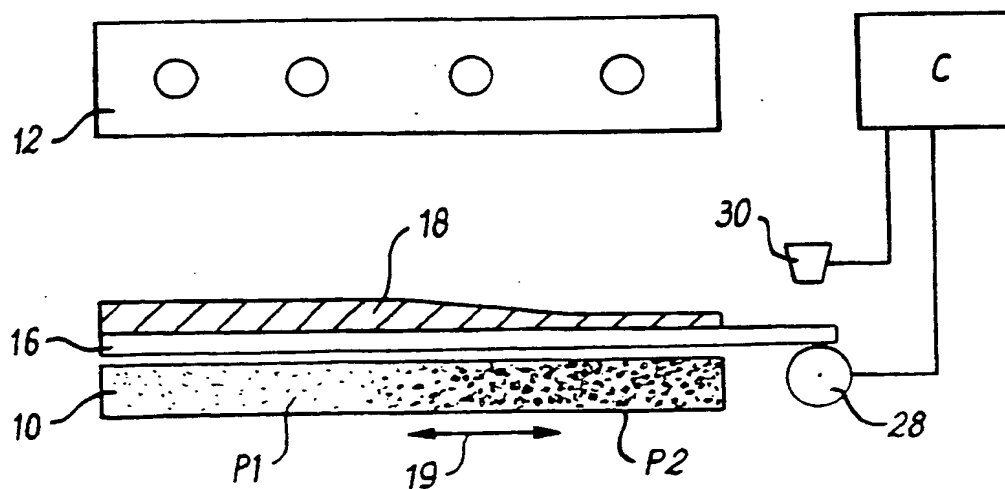
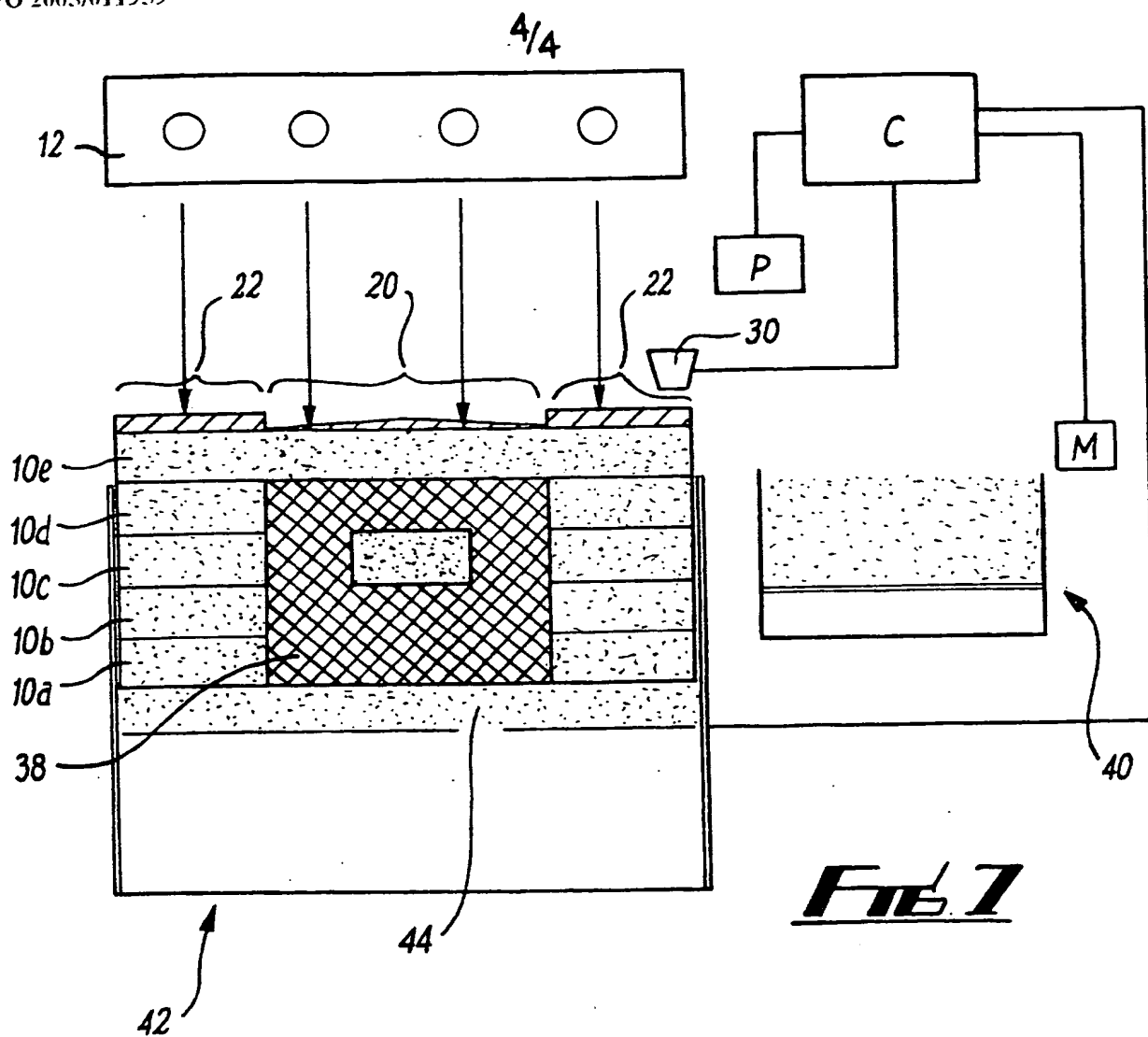


FIG. 4





INTERNATIONAL SEARCH REPORT

Int: International Application No
PCT/GB2004/003142

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B29C67/00 B29C67/02 B29C67/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 01/38061 A (KHOSHNEVIS BEHROKH ; UNIV SOUTHERN CALIFORNIA (US)) 31 May 2001 (2001-05-31)	1,2, 11-13, 15, 19-21, 23-28, 30,33-37 29
Y	claims 1,7-19	
Y	US 6 500 378 B1 (SMITH JEFFREY M) 31 December 2002 (2002-12-31) column 9, line 7 - column 10, line 17 ----- -/--	29

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *Z* document member of the same patent family

Date of the actual completion of the international search

9 December 2004

Date of mailing of the international search report

17/12/2004

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Mathey, X

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2004/003142

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 147 138 A (HOECHSMANN RAINER ET AL) 14 November 2000 (2000-11-14)	1,2, 11-13, 15,16, 19-21, 30,31, 33-37
Y	column 2, lines 20-42; claims; figures	17,18,32
Y	EP 0 535 984 A (SPECTRA GROUP LTD INC) 7 April 1993 (1993-04-07) column 6, lines 21-57	17,18,32
X	US 5 985 204 A (OZAKI MOTOAKI ET AL) 16 November 1999 (1999-11-16) column 4, line 31 - column 5, line 25; figures 4-7,10,15 column 6, lines 25-49 column 7, lines 17-52 example 3	1,2,11, 14, 19-21, 23,28, 33,36,37
X	DE 44 16 901 A (EOS ELECTRO OPTICAL SYST) 16 November 1995 (1995-11-16)	1,2,5,11
Y	column 4; claims; figures	3,4,7,8, 12
A		6
X	US 4 752 498 A (FUDIM EFREM V) 21 June 1988 (1988-06-21)	21, 23-25, 32,35-37
Y	column 6, lines 10-12; figures	3,4,7,8, 12
A	column 6, lines 26-32; claims 7,8 column 3, lines 54-63; claims 15,18,19 column 3, line 38 - column 4, line 6	5,6,9, 10, 13-20, 26-31, 33,34
X	US 2003/052105 A1 (NAGANO KAZUHIKO ET AL) 20 March 2003 (2003-03-20) page 3, paragraph 23 - paragraph 25 page 11, paragraph 131 - paragraph 141 page 15, paragraph 178 - page 16, paragraph 195	1,2, 9-12, 19-25, 28,29, 33,34, 36,37
	----- -/--	

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2004/003142

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002/149137 A1 (JANG BOR ZENG ET AL) 17 October 2002 (2002-10-17) the whole document	1,2, 9-12, 19-25, 33,36,37
A	US 5 182 056 A (SPENCE STUART T ET AL) 26 January 1993 (1993-01-26) column 49, line 22 - column 50, line 23; claims 1-7,23-29	17,18,32

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter. Application No

PCT/GB2004/003142

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 0138061	A	31-05-2001	AU 4301501 A WO 0138061 A1 US 6589471 B1	04-06-2001 31-05-2001 08-07-2003
US 6500378	B1	31-12-2002	NONE	
US 6147138	A	14-11-2000	DE 19723892 C1 AT 234192 T DE 59807431 D1 EP 0882568 A2 ES 2192289 T3	03-09-1998 15-03-2003 17-04-2003 09-12-1998 01-10-2003
EP 0535984	A	07-04-1993	AT 170008 T DE 69226686 D1 DE 69226686 T2 DK 535984 T3 EP 0535984 A1 ES 2121826 T3 HK 1013147 A1 JP 3248006 B2 JP 5212806 A JP 3421788 B2 JP 2002018966 A US 5514519 A US 5677107 A US 5942370 A	15-09-1998 24-09-1998 15-04-1999 28-06-1999 07-04-1993 16-12-1998 22-09-2000 21-01-2002 24-08-1993 30-06-2003 22-01-2002 07-05-1996 14-10-1997 24-08-1999
US 5985204	A	16-11-1999	JP 11005254 A DE 19818469 A1 KR 255330 B1	12-01-1999 29-10-1998 01-05-2000
DE 4416901	A	16-11-1995	DE 4416901 A1 DE 59501852 D1 WO 9531326 A1 EP 0758952 A1 JP 3520310 B2 JP 10505799 T US 5753171 A	16-11-1995 14-05-1998 23-11-1995 26-02-1997 19-04-2004 09-06-1998 19-05-1998
US 4752498	A	21-06-1988	AT 92377 T CA 1319340 C DE 3882981 D1 DE 3882981 T2 EP 0351413 A1 JP 7112712 B JP 2502898 T WO 8806494 A1	15-08-1993 22-06-1993 09-09-1993 31-03-1994 24-01-1990 06-12-1995 13-09-1990 07-09-1988
US 2003052105	A1	20-03-2003	JP 2003080604 A	19-03-2003
US 2002149137	A1	17-10-2002	NONE	
US 5182056	A	26-01-1993	US 5058988 A US 5123734 A US 5059021 A US 5184307 A US 5059359 A JP 3211040 A	22-10-1991 23-06-1992 22-10-1991 02-02-1993 22-10-1991 13-09-1991

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB2004/003142

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5182056 A		AT 160968 T	15-12-1997
		AT 208702 T	15-11-2001
		CA 1334052 C	24-01-1995
		CA 1341214 C	10-04-2001
		DE 68928485 D1	22-01-1998
		DE 68928485 T2	02-07-1998
		DE 68929348 D1	20-12-2001
		DE 68929348 T2	26-09-2002
		DE 375097 T1	29-02-1996
		EP 1106332 A2	13-06-2001
		EP 0375097 A2	27-06-1990
		EP 0860267 A2	26-08-1998
		HK 1003490 A1	30-10-1998
		JP 4506110 T	22-10-1992
		JP 3349508 B2	25-11-2002
		JP 2002316364 A	29-10-2002
		WO 8911085 A1	16-11-1989
		US 5495328 A	27-02-1996
		US 5267013 A	30-11-1993
		AT 154778 T	15-07-1997
		AT 223299 T	15-09-2002
		CA 1338521 C	13-08-1996
		DE 68928141 D1	31-07-1997
		DE 68928141 T2	09-10-1997
		DE 68929423 D1	10-10-2002
		DE 68929423 T2	07-08-2003
		DE 354637 T1	27-06-1996
		EP 1217438 A2	26-06-2002
		EP 0354637 A2	14-02-1990
		EP 0745474 A2	04-12-1996
		HK 1001678 A1	03-07-1998
		HK 1003081 A1	20-06-2003
		IL 89980 A	18-08-1993
		JP 3578388 B2	20-10-2004
		JP 2001353786 A	25-12-2001
		JP 2000015706 A	18-01-2000
		JP 3004667 B2	31-01-2000
		JP 4505588 T	01-10-1992
		KR 229580 B1	15-11-1999
		KR 257034 B1	01-06-2000
		US 6036911 A	14-03-2000
		US 6027682 A	22-02-2000
		WO 8910256 A1	02-11-1989
		US 5609812 A	11-03-1997